

VISUAL EVOKED RESPONSES FOR DIVERS BREATHING  
VARIOUS GASES AT DEPTHS TO 1200 FEET

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## SUMMARY PAGE

### PROBLEM

To measure visual evoked responses (VERs) under hyperbaric conditions while subjects breathed various combinations of oxygen with nitrogen, neon, and helium.

### FINDINGS

There were no differences in brain functioning that were attributable to breathing helium or neon, but pronounced losses occurred with nitrogen.

### APPLICATION

The functioning of the human brain is being monitored at the increased depths and with the unusual breathing mixtures employed by divers to assure there is nothing in these deep-diving conditions that is hazardous to the men.

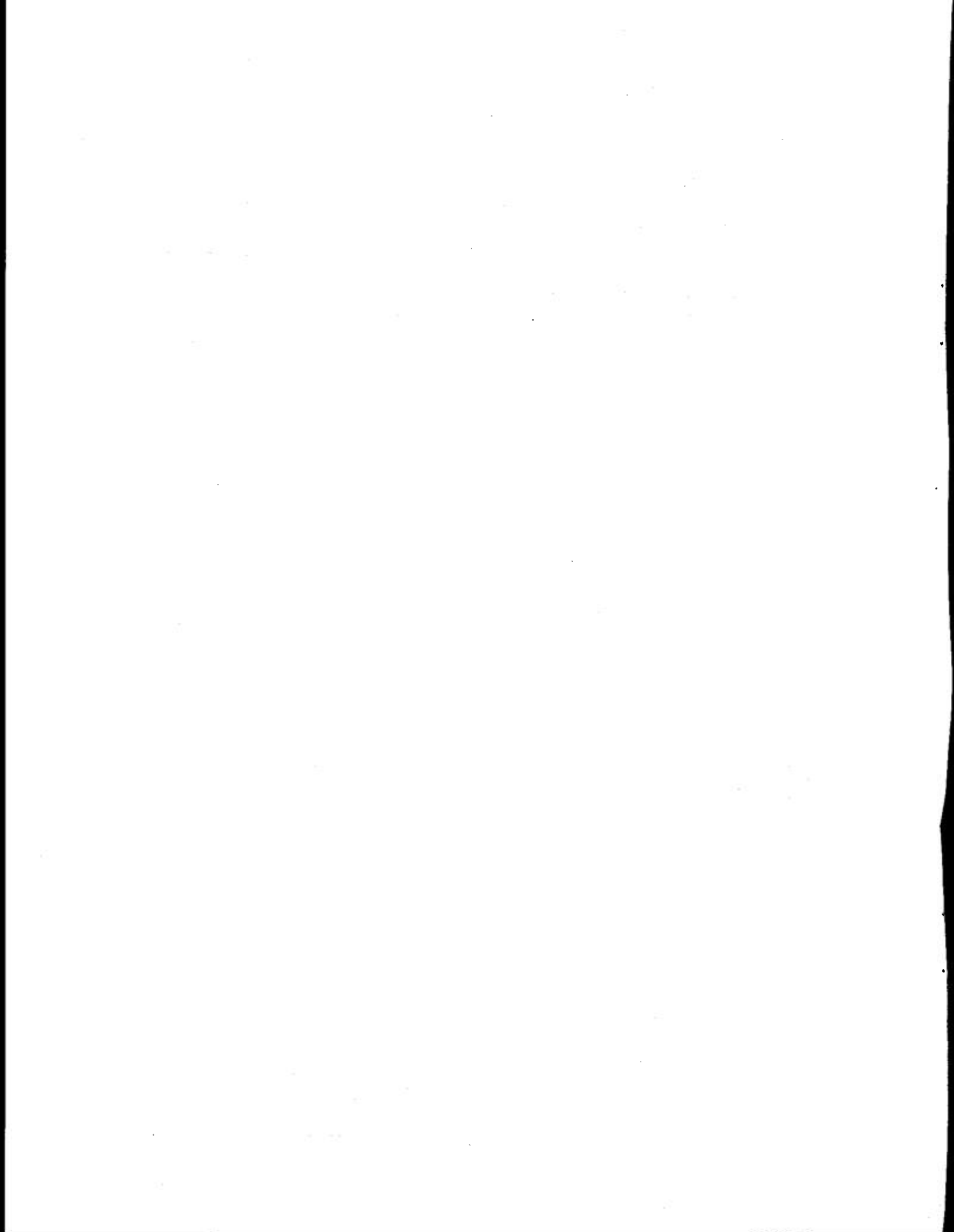
### ADMINISTRATIVE INFORMATION

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## ABSTRACT

Visual evoked responses were recorded from men subjected to hyperbaric conditions simulating 400, 700, 900, and 1200 feet of seawater in a saturation dive conducted at the Institute for Environmental Medicine, University of Pennsylvania, Philadelphia, Pa. Various breathing mixtures were used. At any given depth the VERs were the same for helium-oxygen and neon-oxygen but were sizeably reduced with nitrogen-oxygen, both in amplitude and in regularity. The possibility of an overall loss in VER amplitude with depth deserves further study since one subject did show such a decrement while the other did not.



# VISUAL EVOKED RESPONSES FOR DIVERS BREATHING VARIOUS GASES AT DEPTHS TO 1200 FEET

## INTRODUCTION

The extension of man's diving capabilities to greater depths requires careful monitoring of his physiological state to assure that nothing in the increased depth or unusual breathing mixtures represents an unknown hazard. Such monitoring is routinely carried out by administering a wide variety of physiological and performance tests under experimental dive conditions. While cardiovascular and respiratory functioning are easily tested, brain functioning is more difficult to assess. Electroencephalographic activity is commonly monitored and provides an excellent indication of the subject's general status. Nevertheless, the measure is relatively gross; small changes in the electroencephalogram may go unnoticed and, even if analyzed, their meaning may be unclear. Cognitive performance tests, too, are utilized as an indication of brain functioning but they frequently show no decrements under even extreme stresses; thus a more sensitive measure of incipient disability is desirable.

The evoked cortical potential is being developed as such a measure. Theoretically it holds great promise because it is an objective and direct measure of cortical activity. Empirically it has been shown to be sensitive to a wide variety of environmental stresses.<sup>1-5</sup> We have chosen the visual evoked response (VER) since the visual cortex is most accessible to

electrodes and there is an extensive literature on the variables affecting it.<sup>6,7</sup>

This investigation reports on the visual evoked responses obtained in a deep dive conducted at the pressure chamber of the Institute for Environmental Medicine, University of Pennsylvania, during the summer of 1971. The opportunity for further study of the VER was an excellent one since both pressure and breathing mixtures were variables in the dive.

## PROCEDURE

### VER recording

The visual evoked responses were recorded from bipolar electrodes located at O<sub>1</sub>-C<sub>3</sub> in the International 10-20 System. Outputs from the appropriate terminals of a Grass EEG console were fed to a Technical Measurement Corporation Computer of Average Transients (CAT) for summation. Data were read out from the CAT to a Plotomatic X, Y recorder. The analysis interval, that is, the duration of cortical activity following a stimulus that was summated by the CAT, was one second. One hundred analysis intervals were automatically counted by a TMC pre-set sweep-counter.

The visual stimulus was a pattern of vertical stripes formed of opaque black tape and translucent thin paper. The striped pattern was attached to a

porthole of the Institute for Environmental Medicine's #3 pressure chamber. Subjects viewed the stripes from inside the chamber; the stripes were back-lighted by a Grass PS-2 photostimulator located on top of the porthole. At the subject's viewing distance of three feet, the striped field was 6.5° in diameter and each stripe subtended 45 minutes visual angle.

Two different flash rates were employed to view the striped target: 2 flashes/second and 12 flashes/second. This procedure for recording VERs has been selected as the most sensitive technique for measuring physiological stress, since the two rates yield very different VERs which probably have somewhat different origins.<sup>8,9</sup>

The intensity setting of the Grass photostimulator was 16. This produced a luminance for the bright stripe of 360 footlamberts at 2 flashes per second and 1800 ft-L at 12 flashes per second. Measurement was made by a visual match to a standard using the Luckiesh-Taylor brightness photometer. The duration of the flash was approximately 10  $\mu$ sec.

#### Experimental dive conditions

A saturation dive to 1200 ft lasting 23 days was conducted with compression taking 10 days, followed by five days at the 1200 ft depth, and decompression achieved in eight days. Both compression and decompression stops were made at 400, 700, and 900 ft allowing VER recording at all of these depths. The standard breathing mixture was helium-oxygen; in addition

nitrogen-oxygen and neon-oxygen were breathed by mask at various depths.\*

VERs were recorded from two subjects whenever possible at each of these depths and with each of these gas mixtures. In addition, some measures were made at 200 and 300 ft., during preliminary dives, and control VERs were recorded at the surface prior to and following the main dive. Table I lists the essential variables for each session of VER recording. Complete data were obtained for TL. For SK, a complete profile for helium-oxygen was possible but further runs on nitrogen and neon were discontinued after he became ill while breathing nitrogen at 1200 ft.

#### RESULTS

Sample data, VERs in response to the patterned target illuminated at either 2 or 12 times per second, are shown in Fig. 1. These two conditions yield very different responses. At the slower rate, the entire response to the striped pattern is completed before the next light appears. The response is a complex waveform consisting of negative and positive components which last for at least several hundred milliseconds; two such responses occur in the one second interval. At the faster rate, relatively simple sinusoidal-like responses result which show the same number of

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\*Complete details on the dive protocol will be available in an Institute for Environmental Medicine report.

Table I. Dates on Which VERs were Recorded Under Various Conditions

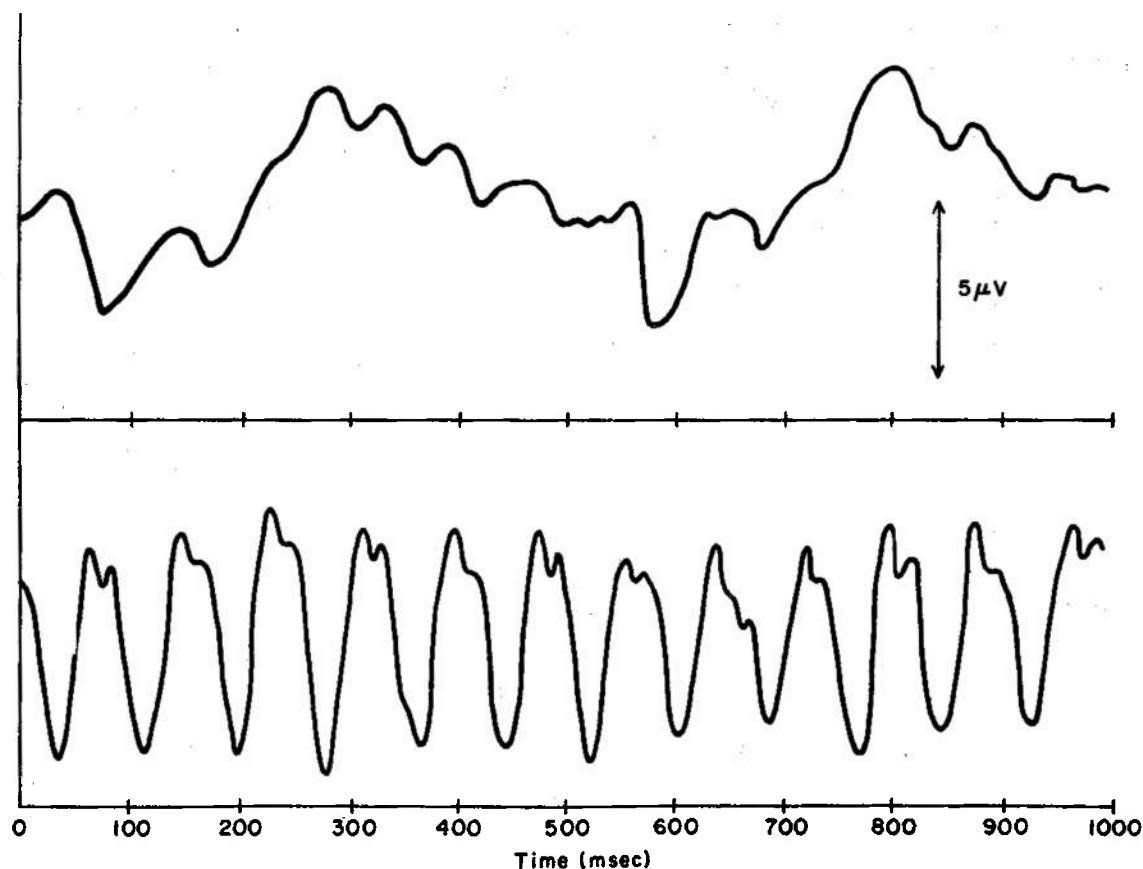
Depth	Helium-Oxygen		Neon-Oxygen		Nitrogen-Oxygen	
	TL	SK	TL	SK	TL	SK
Pre					6/30	6/30
200		6/15				
300	7/1	7/1			7/1	7/1
400	8/7	8/7		8/7	8/8 40% 60%	
700	8/12	8/12	8/12	8/12		
900	8/14	8/14	8/14	8/14		
1200	8/18	8/18	8/18	8/18	8/18	
900	8/24	8/24				
700	8/25	8/25				
400	8/27	8/27	8/27		8/27	
Post	9/1	9/1	9/1	9/1	9/1	9/1

peaks as the rate of stimulus presentation. Advantages and disadvantages accrue to each rate: with rapid stimulus presentation the response is simple, easy to analyze, and individual differences are small but much of the waveform is lost; with the slow rate which does yield the complete response, there are larger individual differences in waveform and evaluation of variations in components is difficult.

#### Targets illuminated 12 times/second

Each VER consists of 12 individual responses which vary slightly in amplitude. The mean of these twelve responses, their standard deviation, and a Z score were calculated for each VER. The Z score =  $\frac{\bar{X} - O}{\sigma}$

where  $\bar{X}$  = the mean of the 12 individual responses,



*Fig. 1 Sample data for Subject TL at the surface illustrating the different types of VER obtained with slow and fast rates of stimulation.*

and  $\sigma$  = their standard deviation.

This score assesses the variability of the 12 individual responses independently of their amplitude. Table II presents these values for the two subjects breathing helium-oxygen at each of the depths.

The mean amplitudes are plotted for the subjects individually in Fig. 2. VERs from two control runs obtained at the surface with subjects breathing air are also shown for comparison.

The data for the two subjects differ from one another to a considerable extent. SK shows a consistent reduction of VER amplitude during compression and a recovery to the original level during the entire decompression period. TL, on the other hand, shows no amplitude differences that are related to depth but rather an extreme variability throughout the course of the experiment. The average of all the VERs obtained with helium-oxygen at all depths for SK was 3.30, or .86 of his surface control runs on air. For TL



Table II. Measures of VERs to Rapid Flash Rate for Subjects Breathing Helium-Oxygen at Various Depths ( $\mu$ volts).

Depth	Subject: TL			Subject: SK		
	$\bar{X}$	$\sigma$	Z	$\bar{X}$	$\sigma$	Z
200				5.75	1.38	4.17
300	6.25	0.98	6.38	4.48	1.18	3.80
400	2.55	0.58	4.40	3.46	1.35	2.56
700	5.05	0.95	5.32	2.52	0.75	3.36
900	3.92	0.90	4.36	3.15	0.80	3.94
1200	4.06	2.06	1.97	3.25	0.78	4.17
900	5.91	0.90	6.57	4.91	1.62	3.03
700	5.38	0.81	6.64	4.99	0.98	5.09
400	3.15	0.96	3.28	4.66	0.89	5.24
0	6.06	0.71	8.54	4.10	1.34	3.06

the comparable value was 3.63, a value of 1.08 times his control amplitudes on air. These values are typical of data for subjects breathing helium-oxygen at the surface.+

Figure 3 shows the consistency of the VERs (Z scores) for the two subjects breathing helium-oxygen at depth. Here the reaction of the two subjects to depth reverses. The poorest Z

score obtained during surface controls is included for comparison.\*\* SK shows no consistent changes in variability as a function of depth, while TL does have some increase in variability during compression with the most variable session occurring at 1200 ft.

+Data obtained at the surface for subjects breathing helium-oxygen are reported in the Discussion section of the paper.

\*\*The largest Z score during control runs is not shown since extremely large Z scores denote very regular responses. Numerically these large values are relatively meaningless since perfect data - i.e., no variability - would result in an infinitely large Z score.

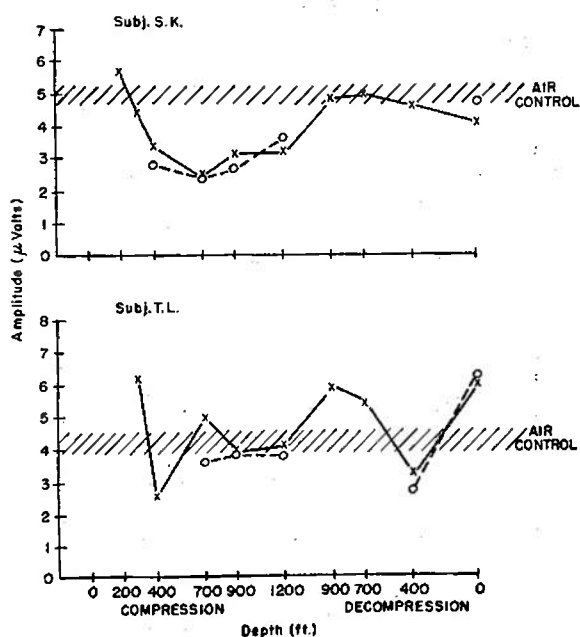


Fig. 2. Amplitudes of VERs to rapid flash rate at depth on Helium (X) and Neon (O).

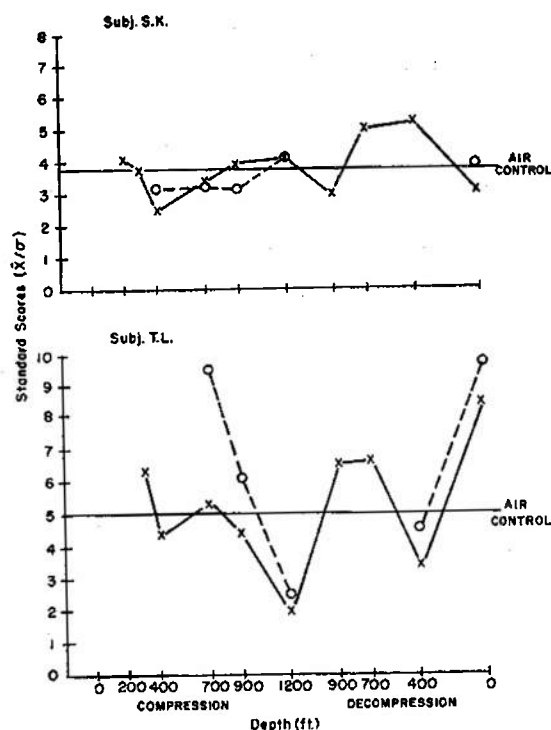


Fig. 3. Regularity of VERs to rapid flash rates at depth on Helium (X) and Neon (O).

Comparable results when the subjects were breathing neon-oxygen at depth are given in Table III and indicated by the dashed lines in Figures 2 and 3. For both subjects the VERs obtained with neon are almost identical to those found with helium. The only difference is that TL shows somewhat less variability with neon than with helium.

Mean amplitudes, sigmas, and Z scores for nitrogen-oxygen mixtures are also given in Table III and are plotted for subject TL in Figure 4. Data for only one depth were available for SK since he was incapacitated several times by breathing nitrogen-oxygen at other depths.

For TL both the amplitude and the regularity of the responses were uniformly depressed at depth compared to the surface controls. The decrements are sizeable and highly significant ( $t = 6.58$ ,  $p < .01$ ). The one record for SK likewise showed a large loss in both amplitude and regularity.

On the other hand, there is no apparent relation between depth per se and the size of the decrement. Nor is the loss related to the partial pressure of the nitrogen; the two largest partial pressures, 145 psi at 1200 ft., and 190 psi at 400, during decompression, did not yield the largest decrements.

#### Targets illuminated 2 times/second

No analyses are presented of the VERs obtained with the flash rate of two per second for two reasons. First, these VERs were of much poorer quality than those with the rapid flash rate, tending to have large concentrations

Table III. Measures of VERs to Rapid Flash Rate for Subjects Breathing Neon-Oxygen and Nitrogen-Oxygen at Various Depths ( $\mu$ volts).

Depth	Subject: TL			Subject: SK		
	$\bar{X}$	$\sigma$	Z	$\bar{X}$	$\sigma$	Z
Neon-Oxygen						
400				2.82	0.88	3.20
700	3.62	0.38	9.53	2.41	0.74	3.26
900	3.82	0.62	6.16	2.70	0.86	3.14
1200	3.75	1.50	2.50	3.62	0.88	4.11
400	2.64	0.58	4.55			
0	6.21	0.64	9.70	4.82	1.24	3.89
Nitrogen-Oxygen						
0				4.75	0.70	6.79
0	4.52	0.90	5.02	5.26	0.54	9.74
300	2.68	0.76	3.53	2.18	1.00	2.18
400 40%	2.30	0.89	2.58			
60%	1.24	0.38	3.26			
1200	2.32	0.86	2.70			
400 98%	2.94	1.24	2.37			
0	3.88	0.66	5.88	4.70	1.25	3.76

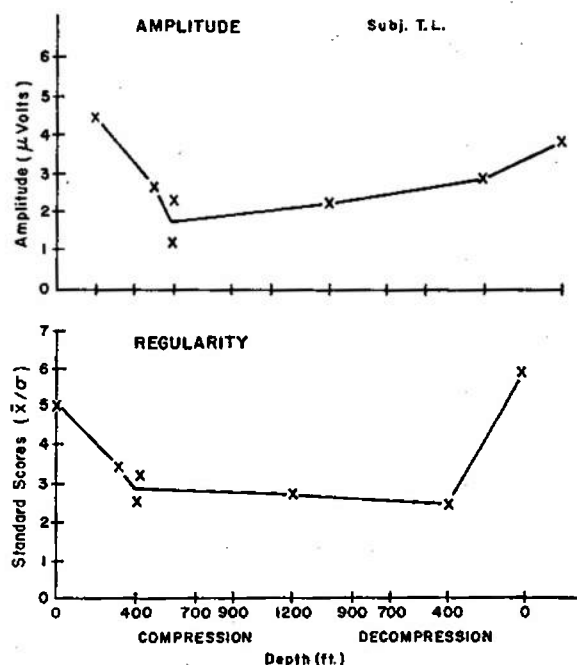


Fig. 4. Amplitude and regularity of VERs at depth for Subject TL on Nitrogen.

of noise throughout the records. Second, the variability of the complete VER is such that numerous repetitions are essential for statistical analysis. However, sample VERs for SK are given in Figures 5 and 6 to illustrate several points. There are no gross differences in the complete VER with depth; differences among control measures at the surface are as large or larger than those among the various depths. Also, there were no large differences in waveform of the VER attributable to breathing helium or neon at a given depth. Finally, the numerous small changes in the summated waveform that occur illustrate the need for many repetitions of the complete VER before their meaning can be evaluated.

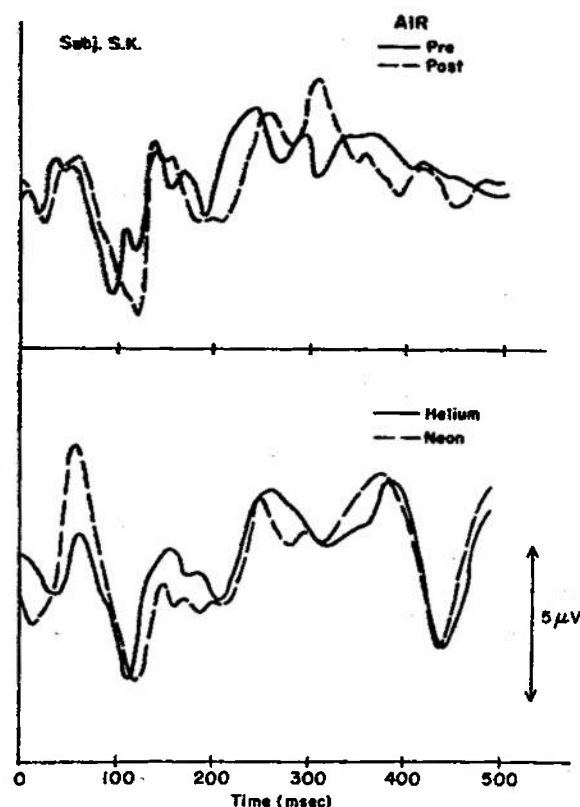


Fig. 5. VERs obtained with slow flash rate for Subject SK at the surface.

## DISCUSSION

The question of whether or not there is a change in VER as a function of depth while breathing helium cannot be answered definitively on the basis of these data. For one subject, SK, there appeared to be a systematic decrement in evoked response amplitude with increasing depth, while for the other subject there did not. Data available in the literature likewise fail to yield a conclusive answer. Commonly, small decrements are reported by subjects breathing helium at depth. For example,

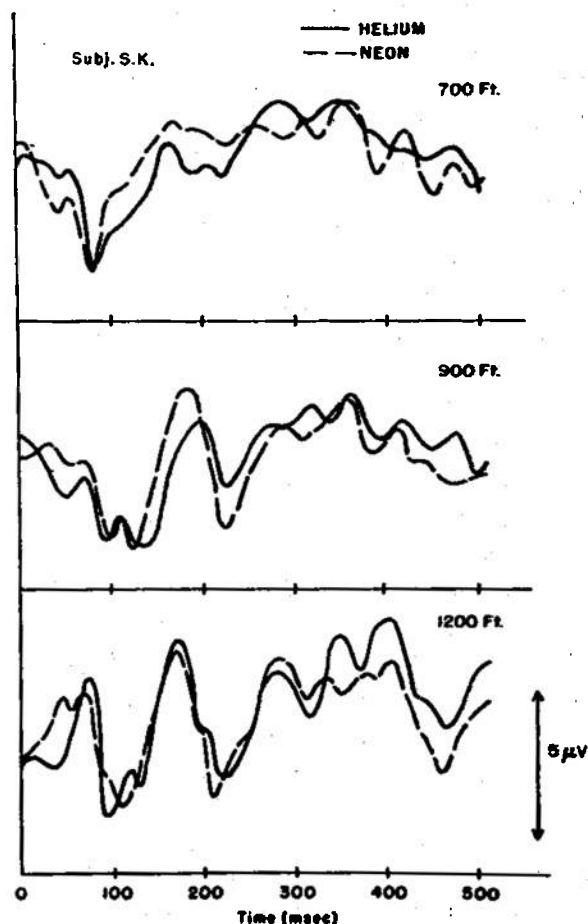


Fig. 6. VERs obtained with slow flash rate for Subject SK at depth on Helium and Neon.

Kinney and McKay found a 16% decrement for divers at 250 ft.<sup>10</sup> Comparable data are available from 8 subjects breathing helium-oxygen at the surface.<sup>11</sup> A comparison of the amplitudes of the responses while breathing helium to control VERs on air yielded a mean decrement of 8.7%. However the range of change varied from a decrement of 34.0% for one subject to an increment of 11.0% for another. In view of this range and of the fact that the 16% decrement was not significantly different from the control data, changes of this size probably should not be taken

too seriously. On the other hand, Bennett, *et al.*, report somewhat larger losses for the auditory evoked response: 29% at 300 ft.<sup>12</sup> and as much as 50-55% at 1500 ft.<sup>13</sup> Further data are obviously necessary to clarify this point and to determine the role of individual differences.

More positively, it is clear in all the results that there were no differences in visual evoked responses that were attributable to breathing helium or neon. Statistical analysis of the VERs to rapid flash rates and qualitative evaluation of the VERs to the slow rate led to the same conclusion.

The results while breathing nitrogen at depth are quite different. The responses to the slow flash rate were often too degraded and noisy to even measure. With the rapid flash rate there was a sizeable and significant decrease in both the amplitude and the regularity of the VERs. Comparable losses have previously been reported for divers breathing air at depths. Bennett, *et al.*,<sup>12</sup> have reported an average amplitude loss for N<sub>1</sub>-P<sub>2</sub> of the auditory evoked response (AER) of 55% at 300 ft; comparable values from Bevan<sup>14</sup> are 63% decrements and from Hamilton & Langley,<sup>15</sup> 57%. For the VER, Kinney & McKay<sup>10</sup> reported both a decrement in amplitude (40%) and in regularity (56%) of responses to rapid flash rates at 250 ft.

Most investigators have attributed the decrements to narcosis since comparable losses were not found in control dives using helium-oxygen. More recently, Ackles and Fowler<sup>16</sup> have

questioned the narcotic explanation since they showed that breathing argon did not result in any greater loss than breathing air at depth.

The results of this experiment would, at first glance, appear to support Ackles and Fowler since there was no systematic relation between the losses and either depth *per se*, or the partial pressure of nitrogen. Figure 7 illustrates this by presenting the data from the present experiment together with the results of the previous one,<sup>10</sup> replotted as a function of partial pressure. An alternative explanation is suggested by the figure: the decrements in this study represent random errors around

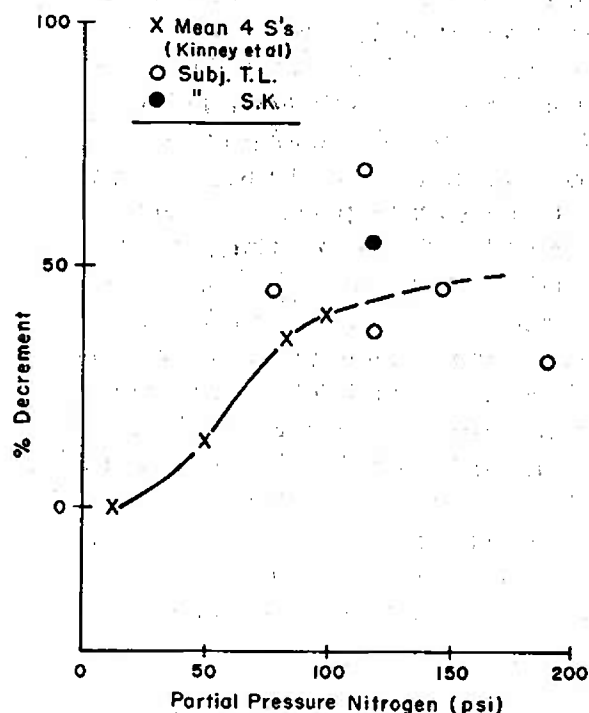


Fig. 7. Decrements in amplitude of VERs to rapid flash rate as a function of the partial pressure of Nitrogen.

an asymptotic value of about 50% loss. There is, in fact, an indication of a plateau in all of the previous studies in which decrement was plotted as a function of depth.<sup>10,12,13</sup> Also, standard deviations reported are large enough to permit such an interpretation. For example, at 7 ATA, decrements calculated for  $\pm 1.0 \sigma$  would range from 30 to 60% for divers breathing both air and argon.<sup>16</sup>

Furthermore, the assumption that the losses in evoked potential amplitude reach an asymptotic level under extreme conditions is more logical than a linear relationship with depth. The latter would predict complete cessation of the evoked response by about 450 ft. or 170 psi of nitrogen; this result would appear unlikely in view of the fact that evoked responses can be recorded from sleeping and lightly anesthetized subjects. This assumption, too, would explain Ackles and Fowler's failure to find a difference between argon and air, since the VERs for both gases had, at 7 ATA, fallen to about the 50% level.<sup>16</sup>

On the other hand, the lesser decrements evidenced by TL at the higher partial pressures of nitrogen might represent a real adaptive improvement. Adaptation, through repeated exposures to air at depth, has been reported frequently for experienced divers;<sup>12,17,18</sup> Adolfson reports adaptation among his divers exposed repeatedly to 400 ft. while breathing air;<sup>19</sup> Walsh and Bachrach report a phenomenon which appears similar for rats at depth.<sup>20</sup>

Compression rate, too, has been implicated in the severity of narcosis

evidenced,<sup>18,19</sup> just as it has in the onset of tremors and EEG abnormalities with helium-oxygen at deeper depths.<sup>13</sup> Thus it is certainly possible that TL did not become as narcotic, when breathing air at the end of the dive, as he did in the beginning. Further data on more subjects is necessary to clarify this issue.

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